Production of high-p_t particles in AuAu and dAu

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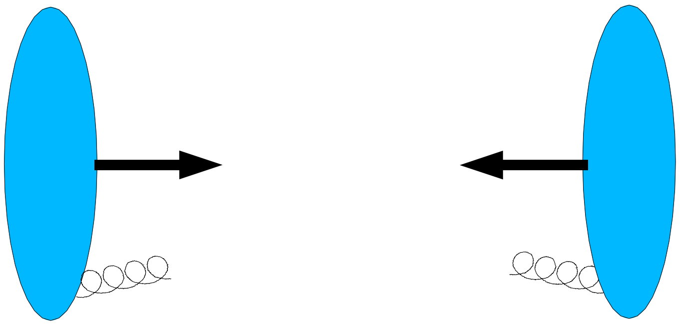
- Motivation. $\longrightarrow$ Medium properties.
- Initial state.
  - nuclear PDF.
  - Saturation ??
- Final state: *jet quenching*.
  - Inclusive particle production.
  - Jet observables.

Space-time picture

Before the collision, initial state: nuclear PDF's.

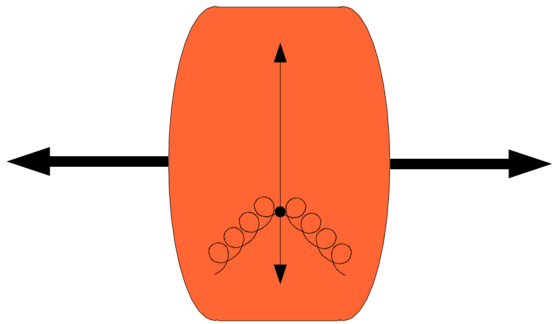


QCD factorization formula:

$$\frac{d\sigma^h_{AB}}{dp_t^2 dy} \sim \sum_{i,j} x_1 f_i^p(x_1, Q^2) \otimes x_2 f_j^p(x_2, Q^2) \otimes \frac{d\sigma^{ij\to k}}{d\hat{t}} \otimes D^{\text{med}}_{k\to h}(z, \mu_F^2)$$

Space-time picture

At $t \sim 0$



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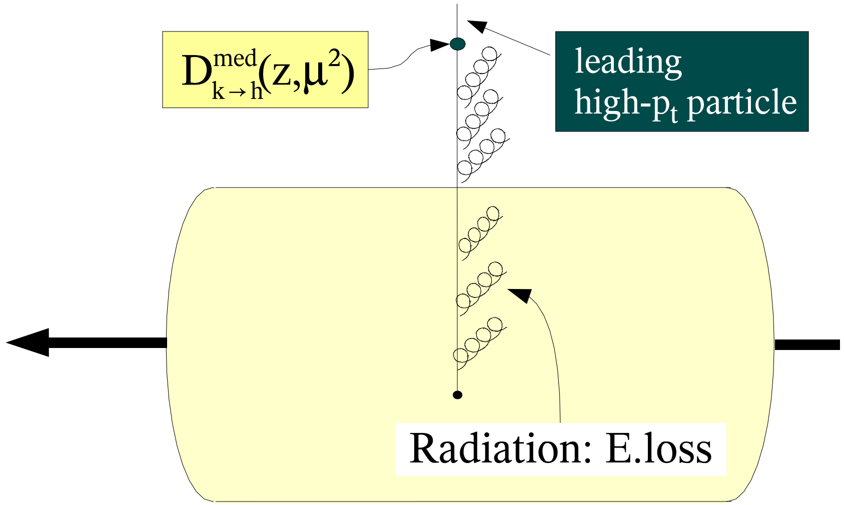
Evolution.



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Initial State

Nuclear PDF: DGLAP approaches

Nuclear modifications to PDF:

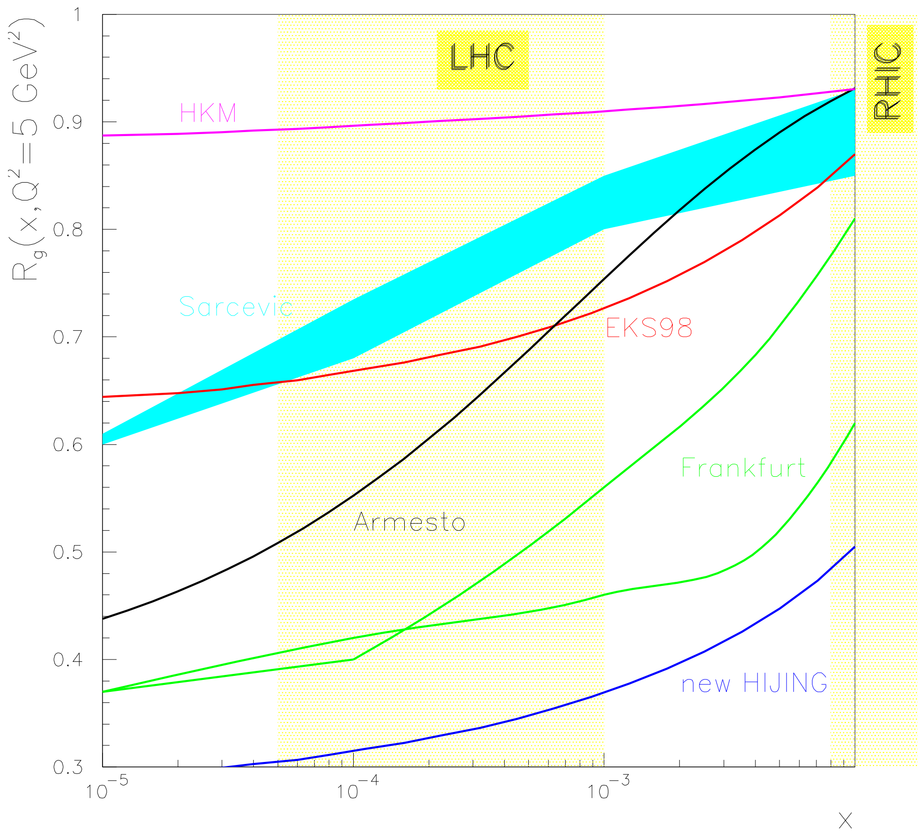
$$R_i^A(x,Q^2) \equiv \frac{f_i^A(x,Q^2)}{f_i^N(x,Q^2)}$$

Several approaches (fits, theoretical...)

Goal of DGLAP approaches:
$\rightarrow$ perform a set of nPDF following the procedure for protons:

- Initial conditions at $Q_0 > \Lambda_{QCD}$
- Evolution by DGLAP equations.

Gluons for Pb, Q^2=5 GeV^2



Accardi *et al.* hep-ph/0308248

Constrains for gluons from DIS data

At small values of x, LO–DGLAP gives

$$\frac{\partial F_2^{p(n)}(x,Q^2)}{\partial \log Q^2} \propto xg(2x,Q^2).$$

This leads to

$$\frac{\partial R^A_{F_2}(x,Q^2)}{\partial \log Q^2} \propto \left\{R^A_g(2x,Q^2) - R^A_{F_2}(x,Q^2)\right\},$$

Q^2–dependence of F_2^{Sn}/F_2^C (NMC)

positive slope $\longrightarrow$

$$\boxed{R^A_g(2x,Q^2) \geq R^A_{F_2}(x,Q^2).}$$

(Eskola, *et al.*, PLB532, 222)

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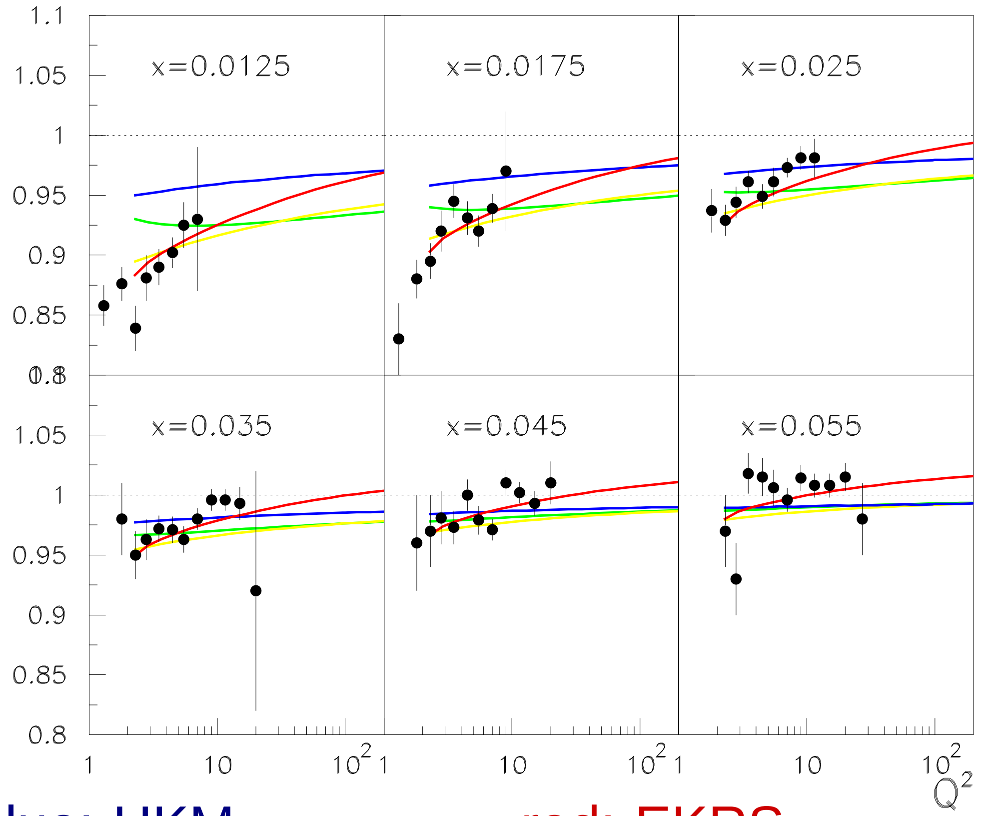
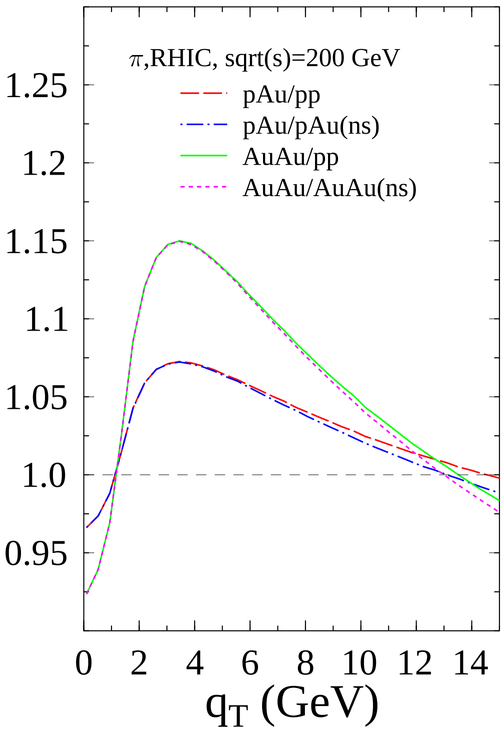


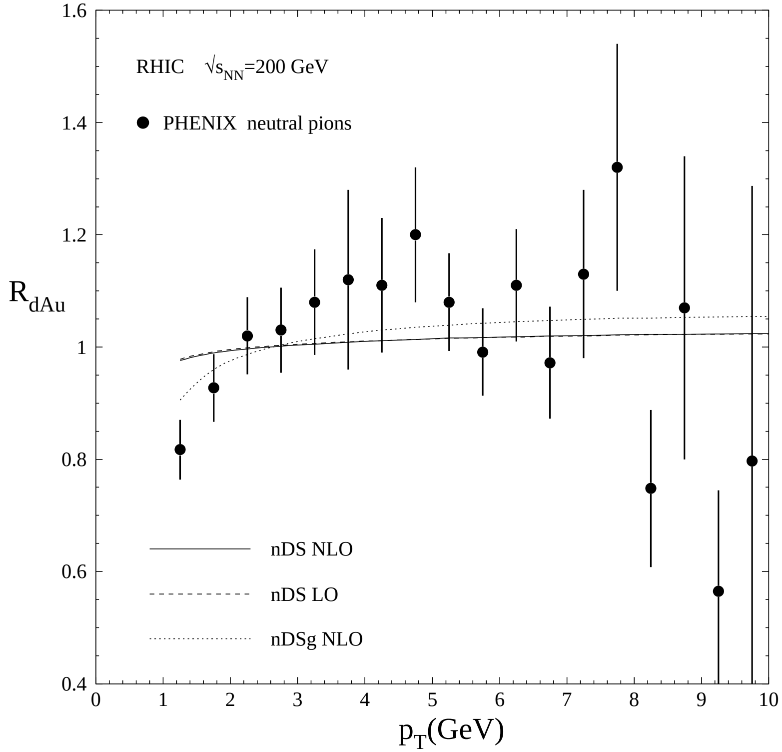
blue: HKM
red: EKRS
green: New HIJING
yellow: HPC

(Full DGLAP evolution)

Comparison with dAu π^0 data

(PHENIX, PRL 91, 072303)





EKRS $\Rightarrow$ small increase ($\sim$ 7%)

(Eskola, Honkanen NPA713 (2003) 167)

(de Florian, Sassot, hep-ph/0311227)

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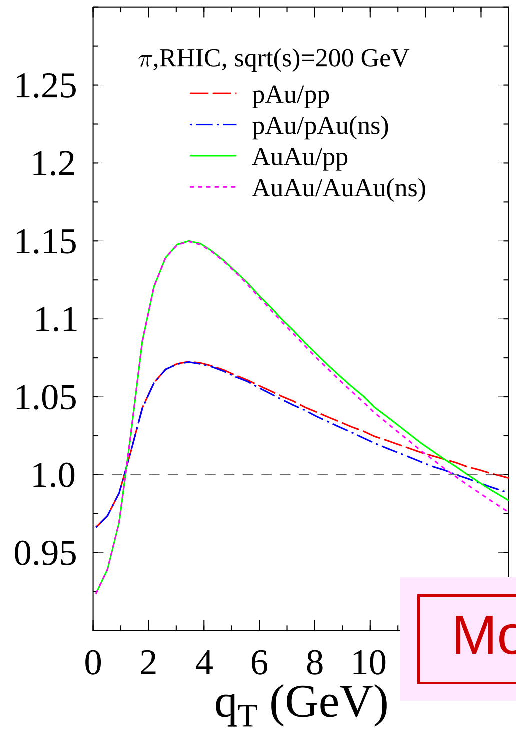

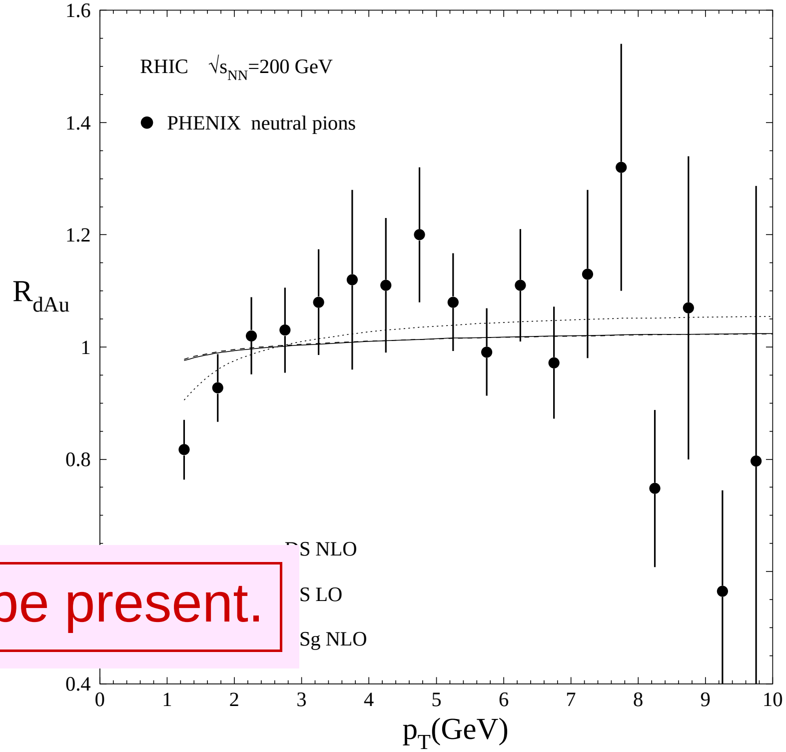

More effects could be present.

EKRS $\Rightarrow$ small increase ($\sim$ 7%)

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Suppression & Saturation: tomorrow's session.

- Saturation physics proposed to explain suppression in central AuAu at $y \sim 0$
  (Kharzeev, Levin, McLerran PLB561, 93)
- dAu data $\Longrightarrow$ this is not realized at $y \sim 0$
- However, predictions in this framework:
  (Albacete, Armesto, Kovner, Salgado, Wiedemann, hep-ph/0307179;
  Baier, Kovner, Wiedemann, PRD68, 054009, hep-ph/0305265 v2;
  Kharzeev, Kovchegov, Tuchin PRD68, 094013 hep-ph/0307037 v2;
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  - Cronin effect (enhancement) included in MV model (no evolution).

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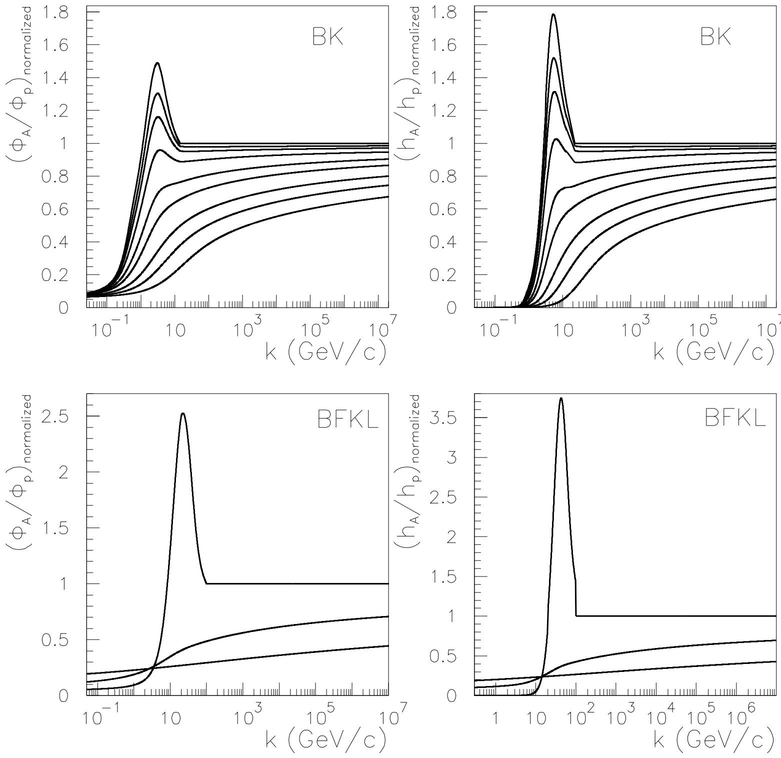
  - Cronin effect (enhancement) included in MV model (no evolution).
  - Small-x evolution (BFKL, BK) suppresses the gluon densities for all p_t very efficiently.

BK and BFKL evolution erases Cronin enhancement

(Albacete, Armesto, Kovner, Salgado, Wiedemann, hep-ph/0307179)

Taken MV as initial condition for BK evolution:



$\Phi \rightarrow$ MV (initial); $h(k) = k^2 \nabla_k^2 \Phi(k)$

$\frac{\alpha_s N_c}{\pi} Y =$0, 0.05, 0.1, 0.2, 0.4, 0.6, 1, 1.4 and 2

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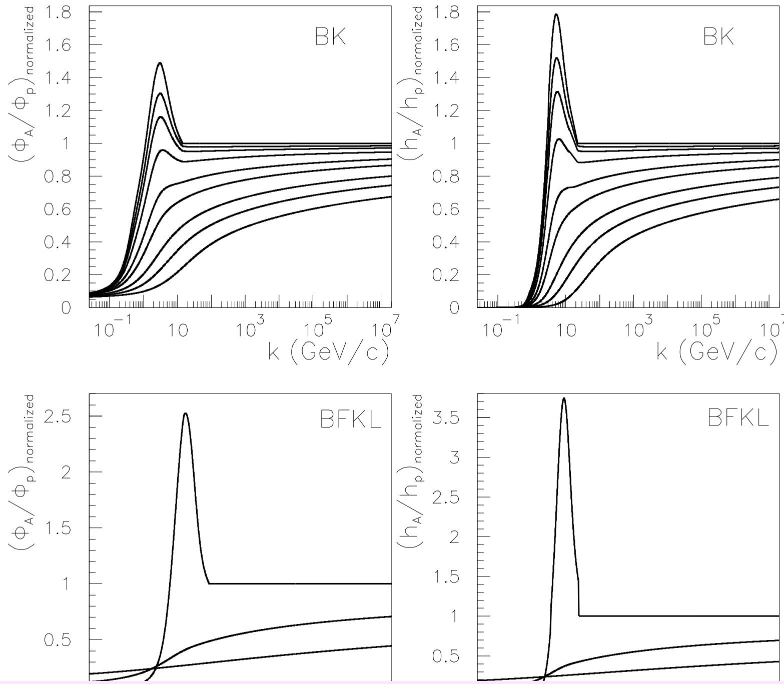

Suppression at forward rapidities $\rightarrow$ BRAHMS???.

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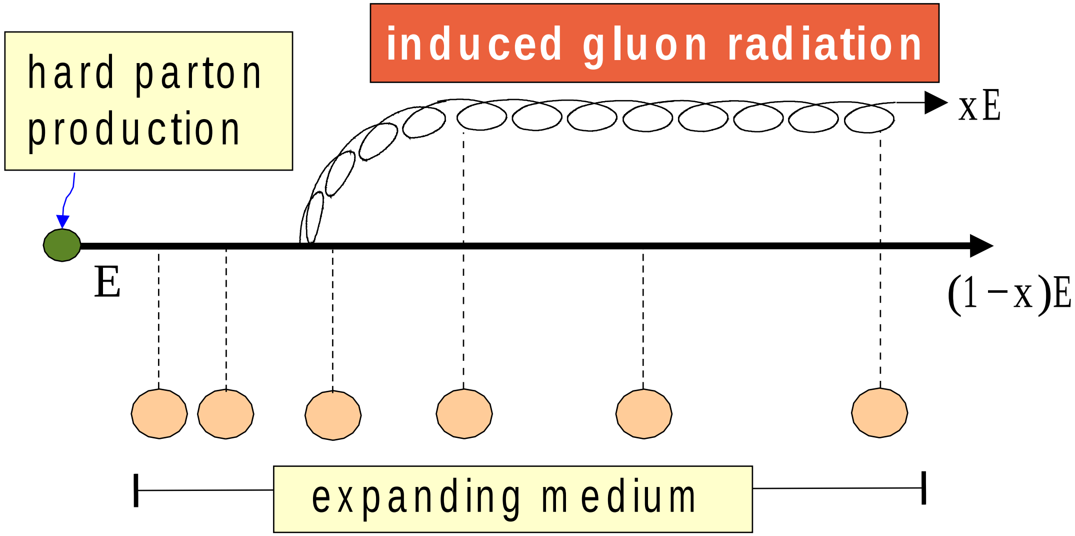
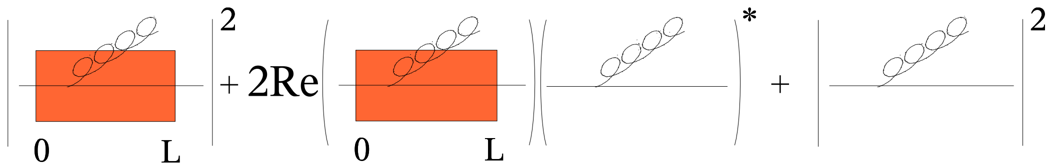
Final State

Medium–induced gluon radiation.

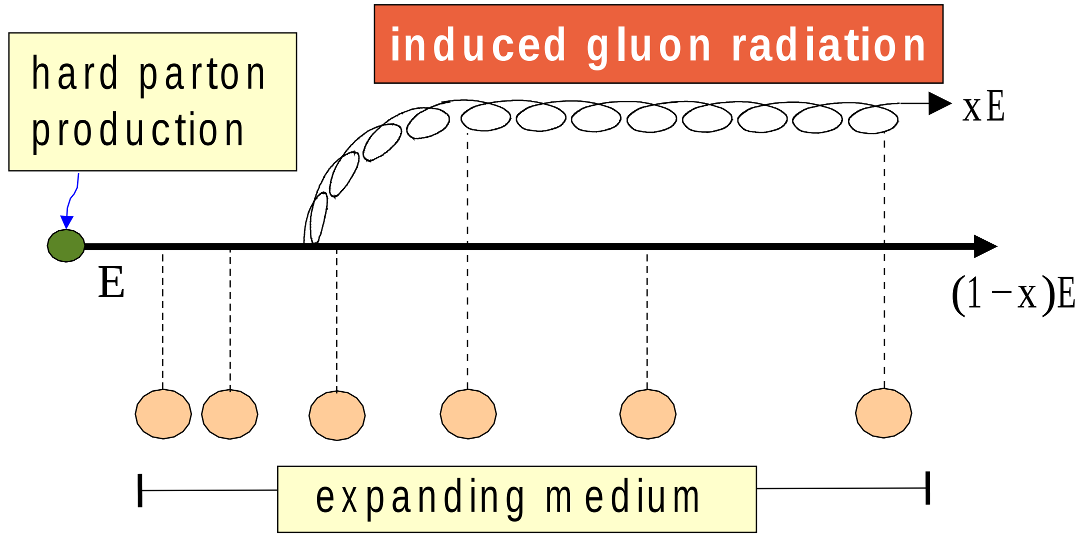


For media of finite length

$$\omega \frac{dI^{tot}}{d\omega\, dk_\perp^2} =$$



Medium–induced gluon radiation.



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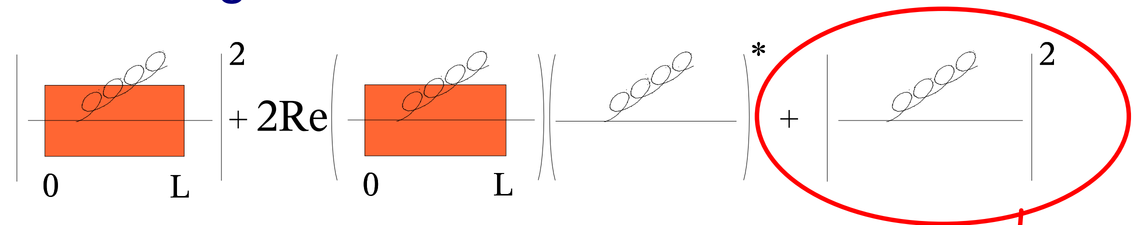


The medium induced gluon radiation

$$\omega \frac{dI}{d\omega dk_\perp^2} = \omega \frac{dI^{tot}}{d\omega dk_\perp^2} - \omega \frac{dI^{vac}}{d\omega dk_\perp^2}$$

Medium: L (length) and $\hat{q}$ (transport coefficient).

Coherent radiation

Coherence effects are important in high energy multiple scattering processes. For a gluon emitted with energy ω and $k_\perp$,

$$\varphi = \left\langle \frac{k_\perp^2}{2\omega} \Delta z \right\rangle \Longrightarrow l_{coh} \sim \frac{\omega}{k_\perp^2}$$

Medium $\longrightarrow$ transport coefficient $\hat{q} \simeq \frac{\mu^2}{\lambda}$, transverse momentum μ^2 per mean free path λ. So,

$$k_\perp^2 \sim \frac{l_{coh}}{\lambda}\mu^2 \Longrightarrow k_\perp^2 \sim \hat{q}L \qquad (\text{for } l_{coh} = L)$$

Let us define $\kappa^2 \equiv \frac{k_\perp^2}{\hat{q}L}\ , \ \omega_c = \frac{1}{2}\hat{q}L^2$

So, the phase for $\Delta z = L \longrightarrow \ \varphi \sim \kappa^2 \ \frac{\omega_c}{\omega}$

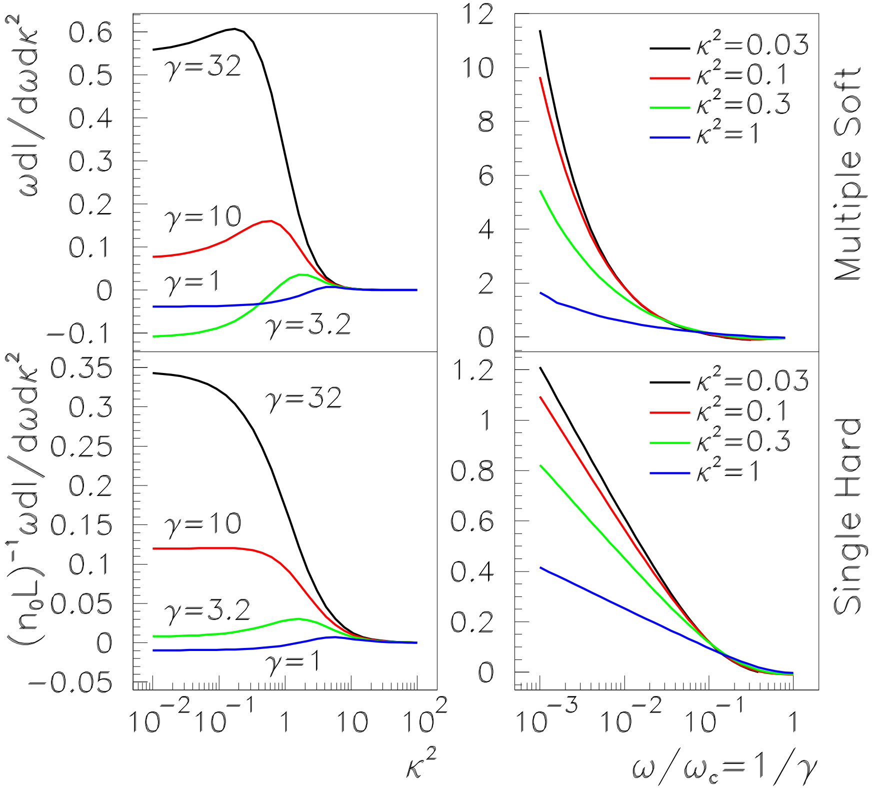
gluon emitted when $\varphi \gtrsim 1 \Longleftrightarrow$ radiation suppressed for $\kappa^2 \lesssim \omega/\omega_c$

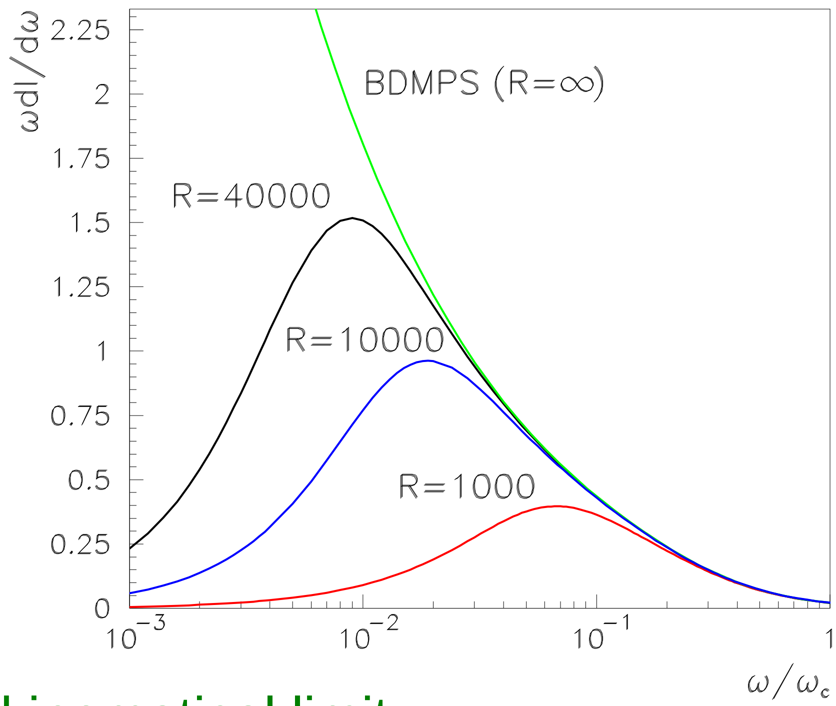
In cold nuclear matter: $Q_{sat}^2 = \hat{q}L \Longrightarrow \kappa^2 = \frac{k_\perp^2}{Q_{sat}^2}$

Gluon energy distributions for quark jets

$$\kappa^2 = \frac{k_\perp^2}{\hat{q}L}\ ,\ \omega_c = \frac{1}{2}\hat{q}L^2$$

$$\omega\frac{dI}{d\omega} = \int_0^\omega dk_\perp \omega \frac{dI}{d\omega dk_\perp}$$





Plateau at small $\kappa \longleftrightarrow$ coherence

gluons $\Longrightarrow$ factor N_c/C_F larger

kinematical limit

$k_\perp \leq \omega \implies R = \omega_c L$ finite

Infrared safe.

Applications: medium-modified FF.

Model:(Wang, Huang, Sarcevic, PRL 77 2537)

$$D^{(\mathrm{med})}_{h/q}(z,Q^2) = \int_0^1 d\epsilon\, P_E(\epsilon)\,\frac{1}{1-\epsilon}\,D_{h/q}(\frac{z}{1-\epsilon},Q^2)\,.$$

$P(\epsilon)$ probability that the hard parton loses a fraction of energy ϵ.
Independent gluon emission approx.: (BDMS, JHEP 0109:033)

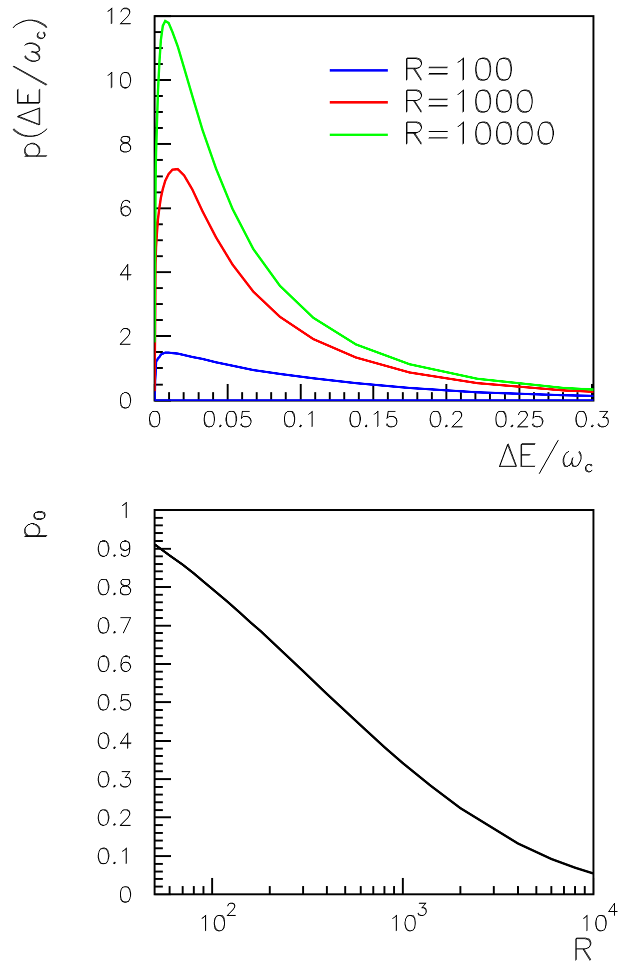
$$P_E(\epsilon) = \sum_{n=0}^{\infty}\frac{1}{n!}\left[\prod_{i=1}^{n}\int d\omega_i\,\frac{dI(\omega_i)}{d\omega}\right]\delta\left(\epsilon-\sum_{i=1}^{n}\frac{\omega_i}{E}\right)\exp\left[-\int d\omega\frac{dI}{d\omega}\right]\,.$$

$$P(\epsilon) = p_0\delta(\epsilon)+p(\epsilon)$$

$p_0 \Rightarrow$ no E.loss and $p(\epsilon) \Rightarrow$ sum for $n\geq 1$.

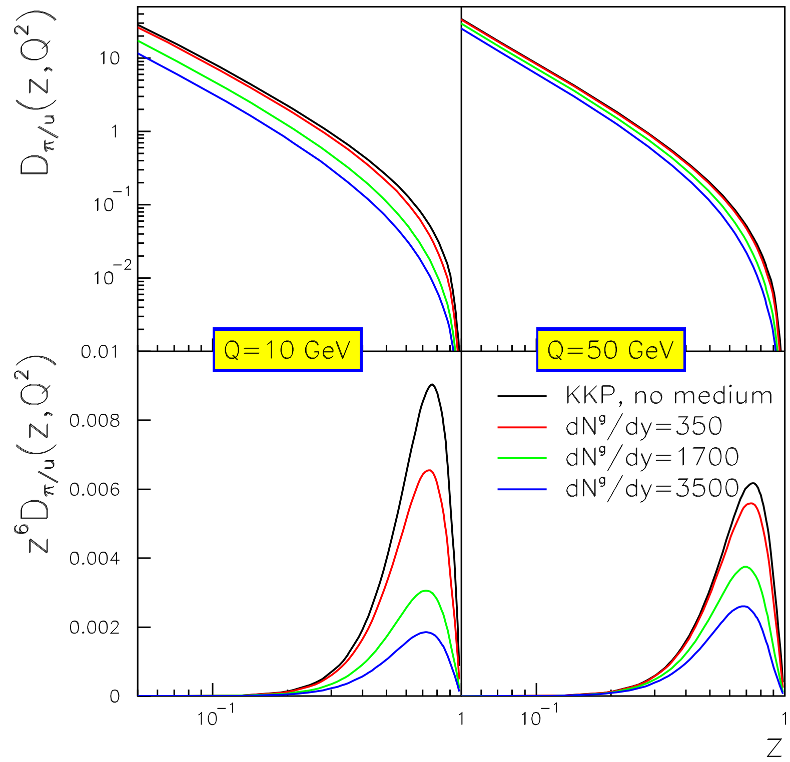
Applications: medium-modified FF.

Quenching weights for quarks.



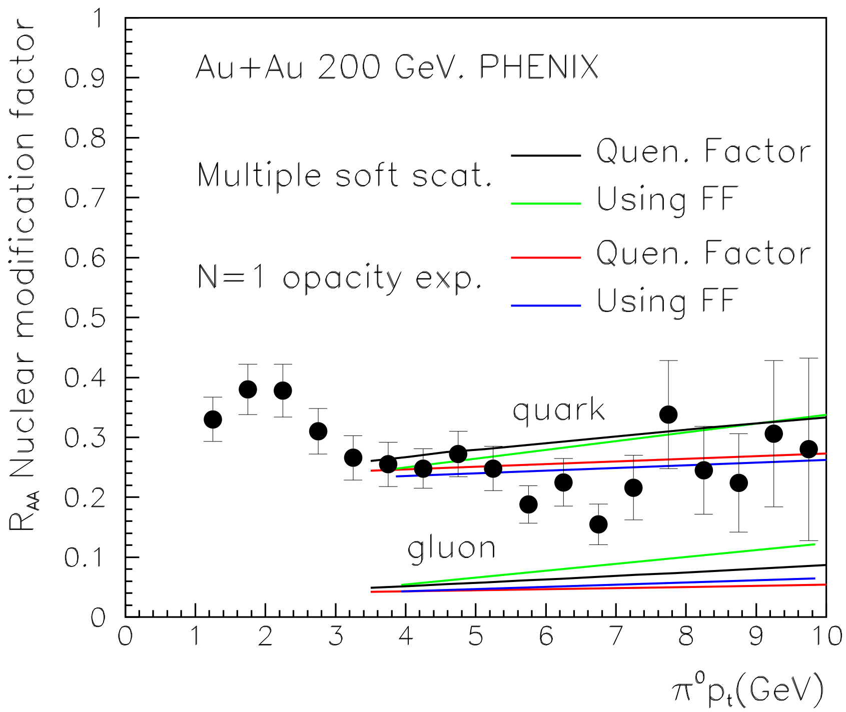
Tabulated: http://home.cern.ch/csalgado

$$R = \frac{\hat{\bar{q}}}{2} L^3 = \frac{L^2}{R_A^2} \frac{dN^g}{dy}$$



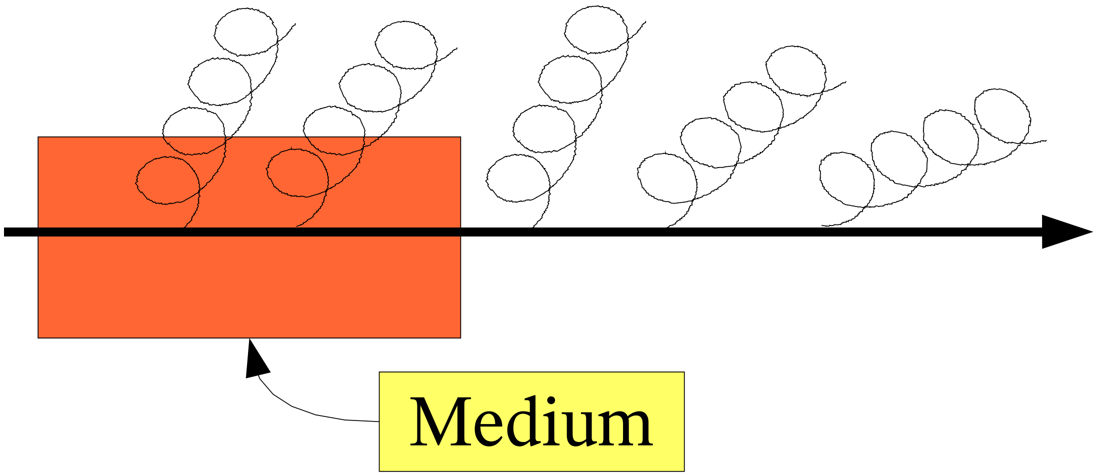
Suppression of $\sim$ 5 for $p_t \sim 5\div7$ GeV $\Longrightarrow$ R$\sim$ 2000.

Applications: Comparison with PHENIX data.



- ⇛ Factor 5 suppression needs R$\sim$ 1000$\div$2000. But small-p_t region not well reproduced: additional effects? (shadowing, Cronin ...) Gyulassy, Levai, Vitev, Wang, Arleo ...
- ⇛ Smallest values of p_t are in the limit of applicability of the calculations.
- ⇛ Slope and magnitude of the effect are ok.

Jets



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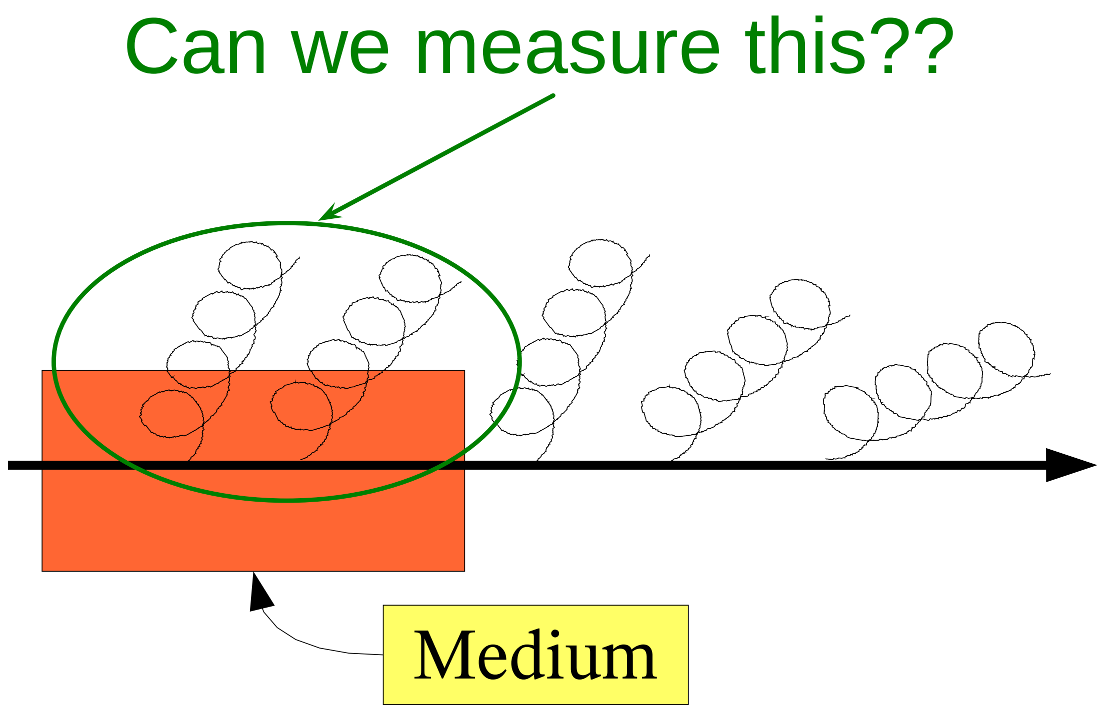


Jet shapes

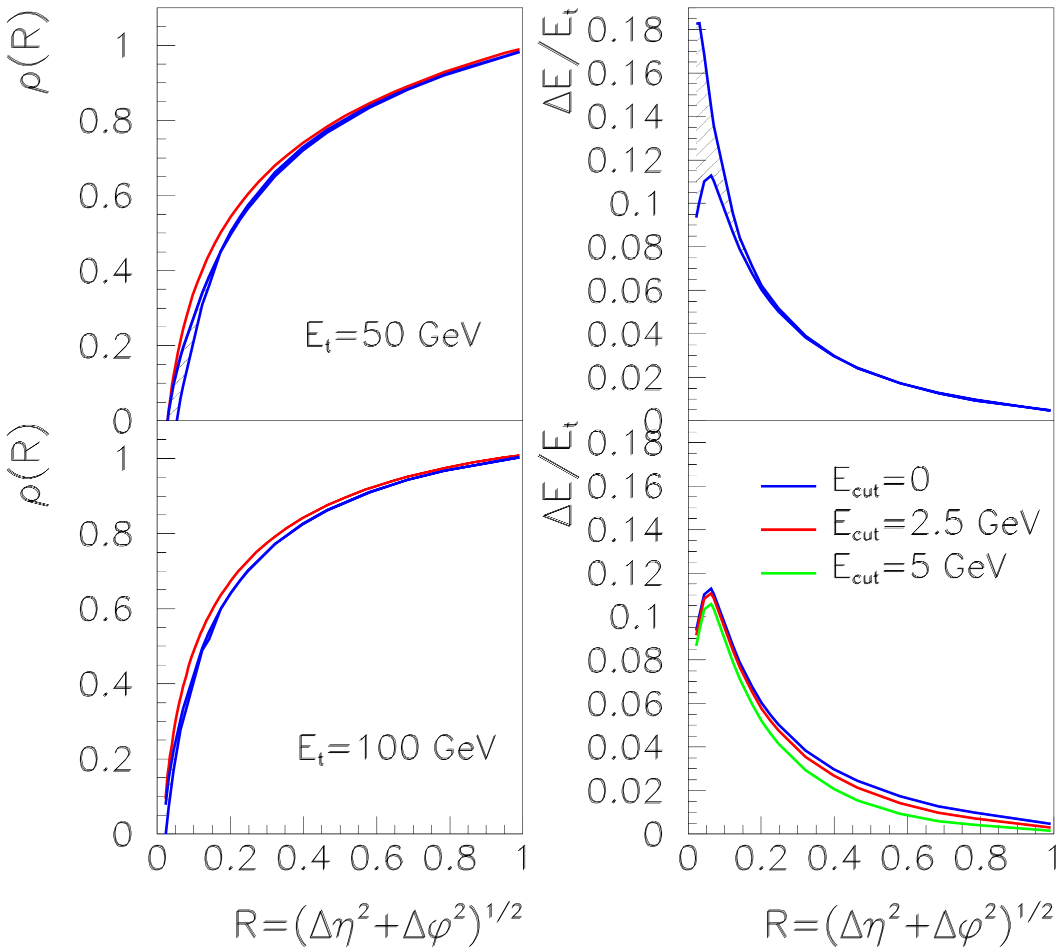
$\rho(R)$, fraction of the jet energy inside a cone $R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$

$$\rho_{\rm vac}(R) = \frac{1}{N_{\rm jets}} \sum_{\rm jets} \frac{E_t(R)}{E_t(R=1)}$$

$$\rho_{\rm med} = \rho_{\rm vac} - \frac{\Delta E_t(R)}{E_t(R=1)}$$

Small modification $\rightarrow$ can jet energy be determined experimentally above background??
Scaling with number of collisions for large cone angle.

Small sensitivity to IR cuts!
(Salgado, Wiedemann hep-ph/0310079)



Vacuum D0 data: Fermilab-PUB-97/242-E

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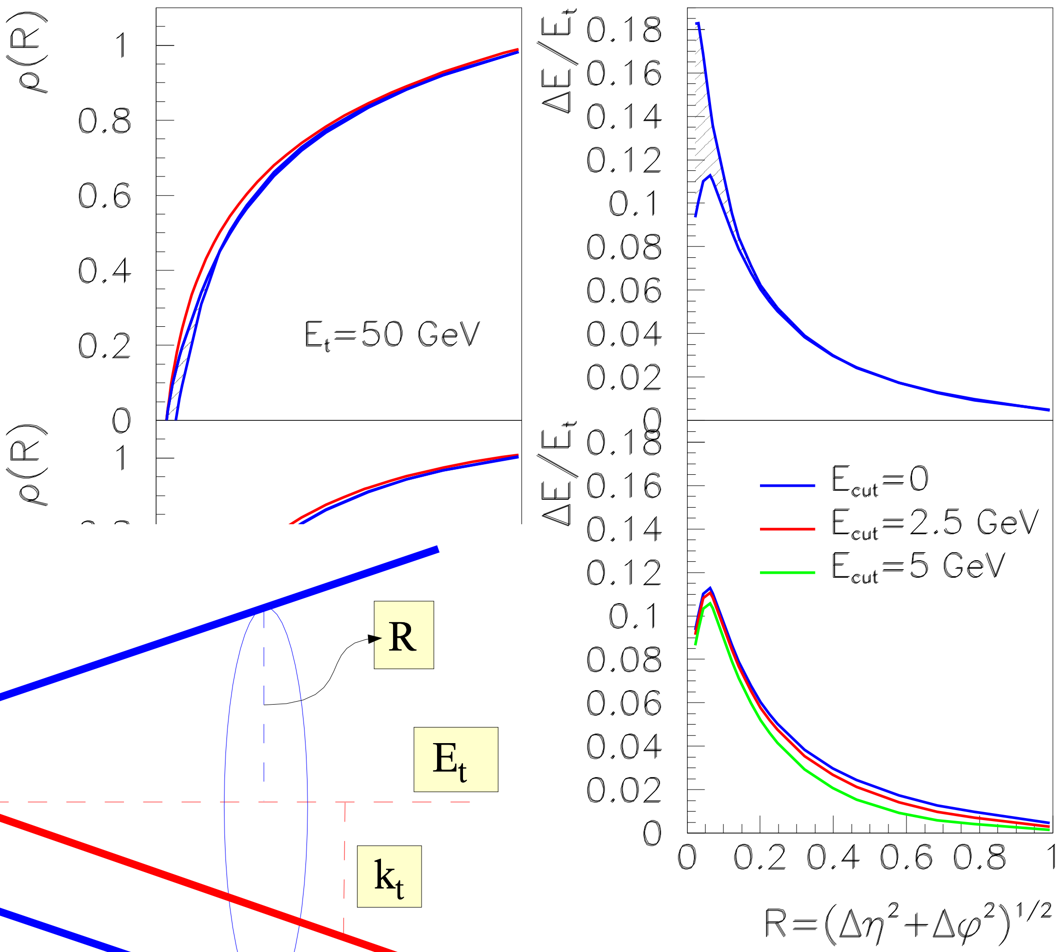

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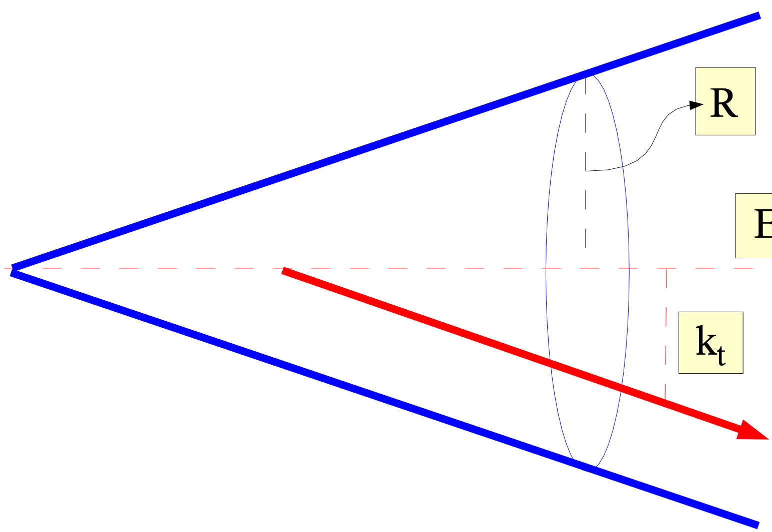

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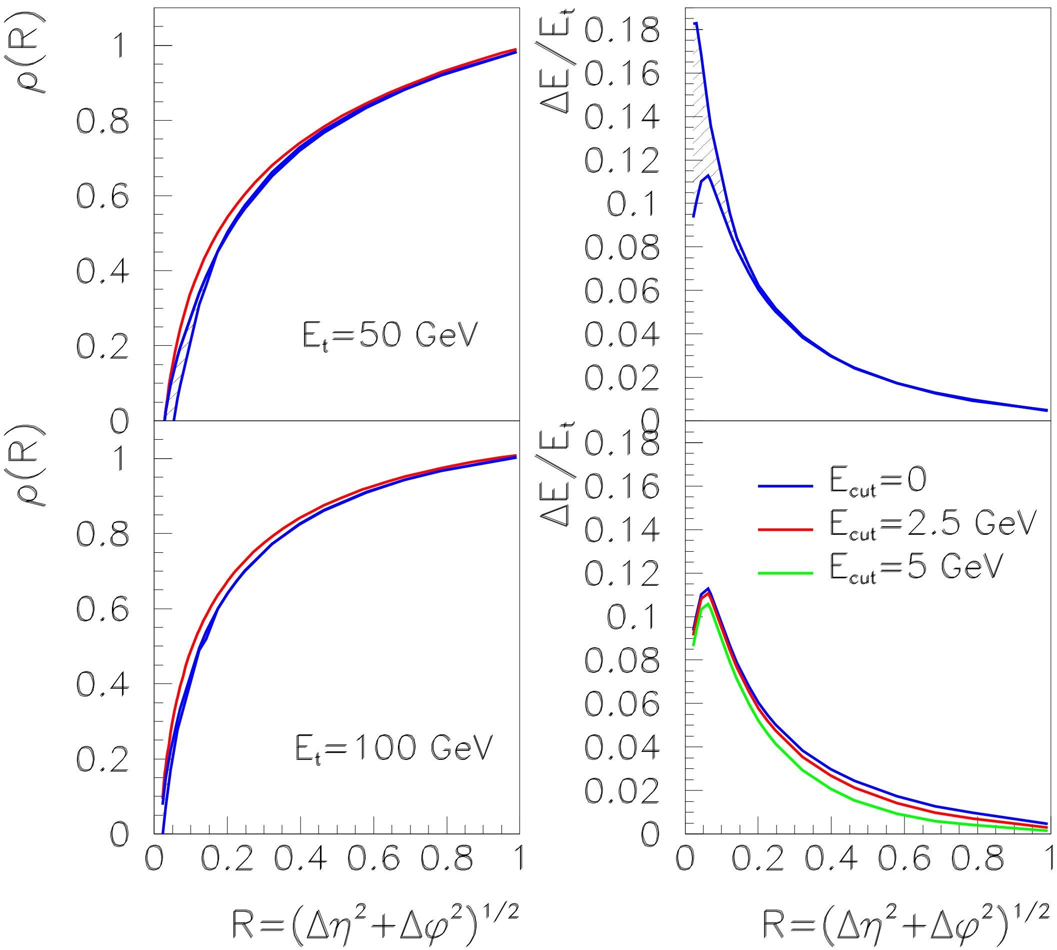

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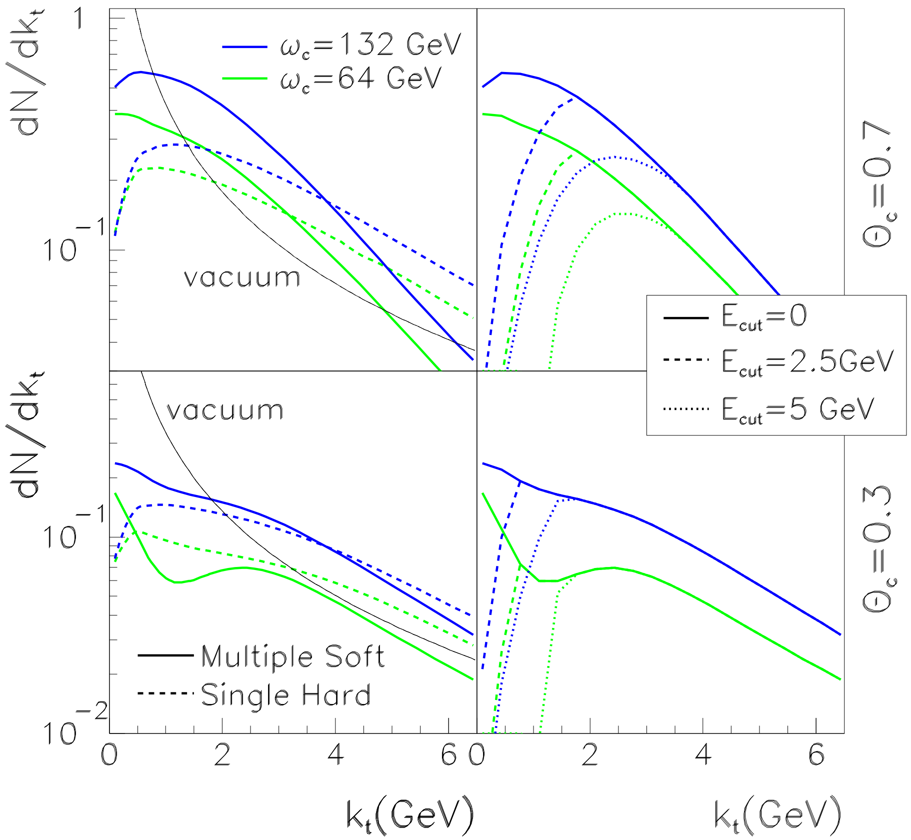
Gluon multiplicity inside the jet.

The characteristic angular distribution of the medium–induced gluon radiation could be better observed in the quantity

$$\frac{dN^{\rm jet}}{dk_\perp} = \int_{k_\perp/sin\theta_c}^{E} d\omega \frac{dI}{d\omega dk_\perp}$$

For the vacuum we simply use

$$\frac{dI_{\rm vac}}{d\omega dk_\perp} \sim \frac{1}{\omega}\frac{1}{k_\perp}$$



(100 GeV jet)

Needs a more quantitative analysis.

But, effect based mainly on kinematics!

Conclusion

- High-pt particle production is affected by the medium $\rightarrow$ good probe to study its properties.
- RHIC high-p_t results strongly point to a final state effect in central AuAu.
  - In agreement with jet-quenching interpretation.
  - dAu data essential.
- DGLAP+NMC $\Rightarrow$ not very strong gluon shadowing for $x \gtrsim 0.01$.
- Small-x evolution removes Cronin very fast $\Rightarrow$ forward rapidities (?)
- Medium–induced gluon radiation computed for realistic length & kinematics: We recover BDMPS for $R \rightarrow \infty$. Small IR-sensitivity.
- Angular dependence of the radiation $\longrightarrow$ study Jets.
- Jet shapes $\rightarrow$ Can these effects be seen @ RHIC?
  - Small effect in the azimuthal redistribution of jet energy.
  - Gluon multiplicities inside the jets could be a clean observable.

DGLAP analyses

Comparison EKS, HKM, nDS (de Florian and Sassot, hep-ph/0311227)